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Grunsky. Type of the Panama Canal.

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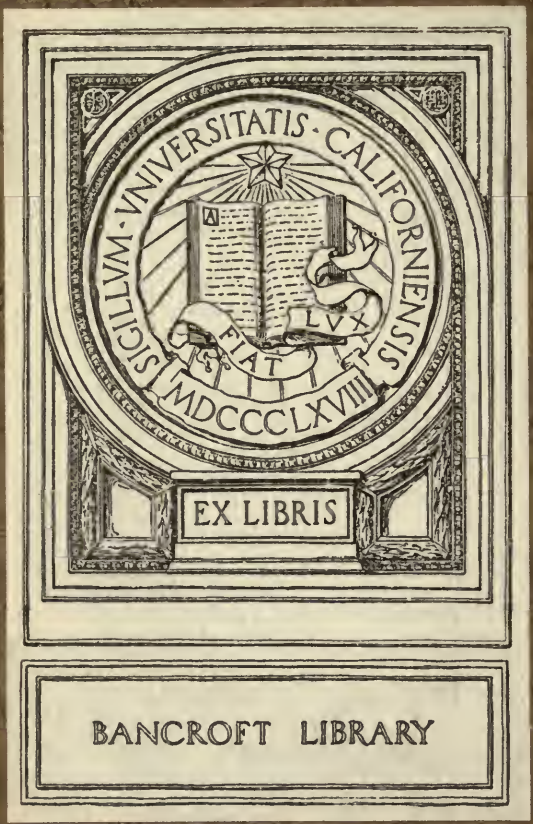

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THE TYPE OF THE PANAMA CANAL

By C. E. GRUNSKY, 1855-

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THE TYPE OF THE PANAMA CANAL

By C. E. GRUNSKY

MEMBER OF THE ISTHMIAN CANAL COMMISSION OF 1904

UNDER the law of June 28, 1902, generally referred to as the Spooner act, which authorizes the construction of an interoceanic canal President Roosevelt appointed, in March, 1904, the following commissioners: Rear Admiral John G. Walker, U. S. Navy (retired), chairman; Major Genl. Geo. W. Davis, U. S. Army (retired); Col. Frank J. Hecker, of Detroit; Major Benjamin M. Harrod, civil engineer of New Orleans; Professor Willam H. Burr, of Columbia University, New York; Wm. Barclay Parsons, of New York; and the writer, of San Francisco.

The Spooner act empowers the president to purchase the canal properties upon the Panama route at a cost not exceeding $40,000,000, or, in the event of failure to do this, to enter into negotiations with the republics of Costa Rica and Nicaragua for a right of way on what is commonly known as the Nicaragua route.

Provision was made for the prosecution of the work of canal construction by the president, acting through and with the aid of a canal commission. An appropriation of $10,000,000 was carried by the act for use upon either of the two routes, and Congress was pledged to make additional appropriations as required up to $135,000,000 in case the Panama route was adopted and not to exceed $180,000,000 for work on the Nicaragua route. The secretary of the treasury is authorized to borrow from time to time, as funds may be required, the sum of $130,000,000, issuing therefor coupon or registered thirty-year bonds in such form as he may prescribe, redeemable after ten years, bearing interest at two per centum per annum.

The passage of the Spooner act by Congress, followed the submission of a report by the canal commission of 1899–1901, which recom-

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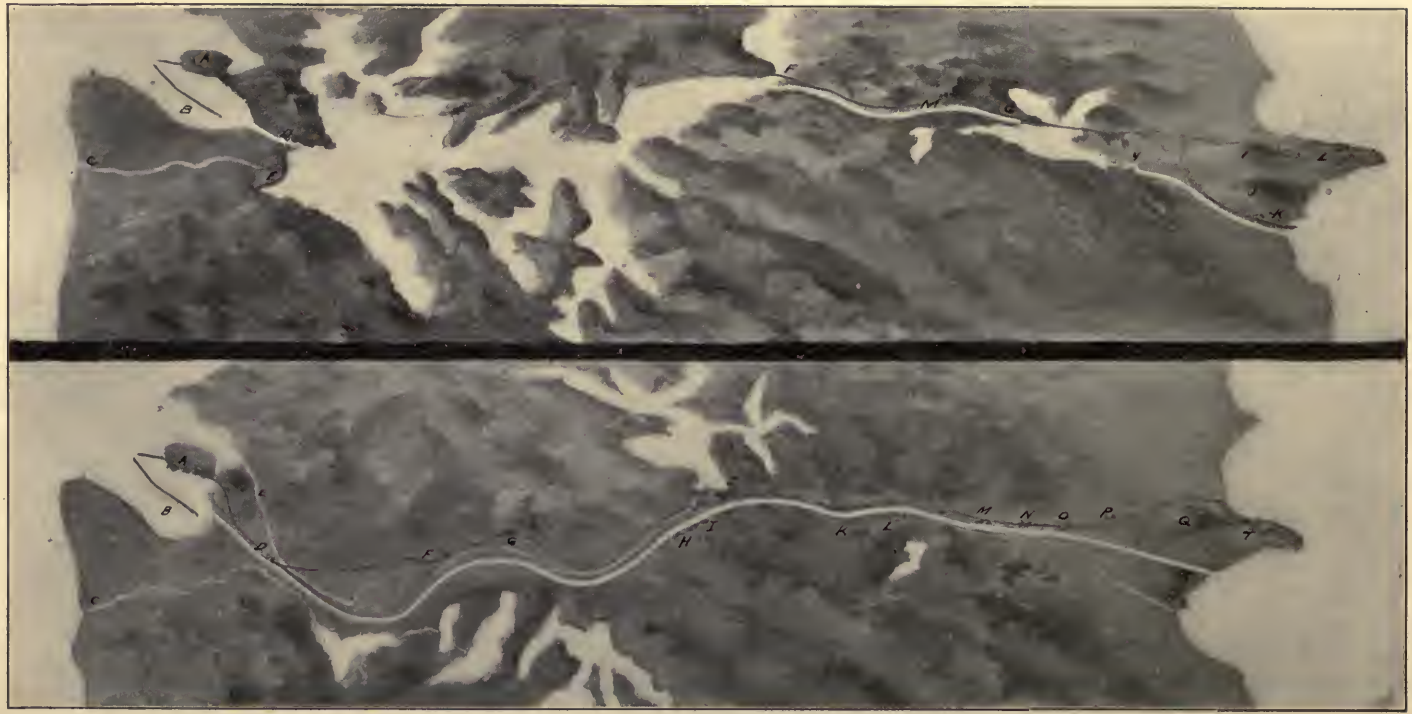


UPPER SKETCH—LOCK CANAL. *A*, Colon; *B*, Limon Bay; *C*, mouth of Chagres River; *D*, Gatun Locks; *E*, Gatun Dam; *F*, Gamboa; *G*, Pedro Miguel Lock; *H*, Miraflores Locks; *I*, Ancon Hill; *J*, Sosa Hill; *K*, La Boca; *L*, Panama; *M*, Culebra Cut.

LOWER SKETCH—SEA-LEVEL CANAL. *A*, Colon; *B*, Limon Bay; *C*, mouth of Chagres River; D, Gatun; E, Chagres Diversion; F, Bohio; *G*, Frijoles; *H*, Gorgona; *I*, Matachin; *J*, Gamboa Dam; *K*, Empire; *L*, Culebra; *M*, Paraiso; *N*, Pedro Miguel; *O*, Miraflores; *P*, Corozal; *Q*, Ancon Hill; *R*, Sosa Hill; *S*, La Boca; *T*, Panama.

mended the acquisition by the United States of the rights and properties of the New Panama Canal Company. This recommendation was the direct result of an offer of the canal company to sell all its rights and properties for the sum of $40,000,000. The actual transfer of the canal properties to the United States took place on May 4, 1904.

The great engineering question before the commission, above named, related to the type of canal. Should the canal be built at sea-level or should it cross the backbone of the isthmus at the elevation suggested by the investigating commission of 1899–1901, and apparently contemplated by the Spooner act, with a summit level at 85 feet, or should it be a lock canal with some other elevation of its summit section? This question and the administration's course in setting aside the recommendation of a majority of the board of consulting engineers and adopting the plan of a lock-canal with a summit at the elevation suggested by the commission of 1899 and advocated by the minority members of the board of engineers are still fruitful of discussion.

A review of the proceedings leading to the solution, and a presentation of some of the physical features of the problem, as disclosed by the proceedings, may prove an aid to a better understanding of the present situation.

Relating to the kind of canal to be constructed the law provides:

> The President shall then, through the Isthmian Canal Commission . . . cause to be excavated, constructed and completed, utilizing to that end, as far as practicable, the work heretofore done by the New Panama Canal Company, of France, and its predecessor company, a ship canal from the Caribbean Sea to the Pacific Ocean. Such canal shall be of sufficient capacity and depth as shall afford convenient passage for vessels of the largest tonnage and greatest draft now in use, and such as may reasonably be anticipated, and shall be supplied with all necessary locks and other appliances to meet the necessities of vessels passing through the same from ocean to ocean. . . .

It was recognized by the commission of 1904 that under the Spooner act as quoted, a departure, to some extent at least, from the project which the earlier commission had outlined as a basis for comparative cost estimates was authorized and proper. It was incumbent upon the commission to determine whether a canal with summit level at 80 or 60 or 30 feet would not, all things considered, be better than the canal with summit level at 85 feet. It was therefore necessary to regard the entire question of type of canal an open one to be solved by the selection of that type and that summit elevation which would best fulfill all requirements. It was realized that this question required careful consideration from every standpoint, particularly in relation to its serviceability, to time required for construction, to first cost and to the cost of operation and maintenance with due regard to the importance of early completion, and reliability of service after completion.

In entering upon a preliminary discussion of these matters the lack

SEAGOING SUCTION DREDGE *Ancon* TAKING ON COAL NEAR DRY DOCK AT CRISTOBEL. This and other photographs are from the Annual Reports of the Commission.

of adequate data was sorely felt by the members of the commission and it was soon found that no satisfactory conclusion could be reached without supplementing by additional exploration with the auger and otherwise, the information disclosed by records of surveys, borings and shafts, which had been made by the engineers of the French canal companies. There had been no explorations to sea-level by shaft or by borings in the central sections of the canal yet this information was now of paramount importance for the determination of safe slopes for the sides of the deep cuts. In the absence of such information no satisfactory conclusion could be reached relating to the amount of material that would have to be excavated to maintain a great open cut at Culebra. The side slopes of this cut must be so flat that they will stand permanently. They should be as steep as they can safely be held in order that the quantity of excavation may not be unnecessarily increased. For the solution of this problem, it was necessary to know not only the character of all material to be encountered down to sea-level, but to a depth of over 40 feet below sea-level. Incomplete or unreliable data would throw more or less doubt upon the conclusions reached.

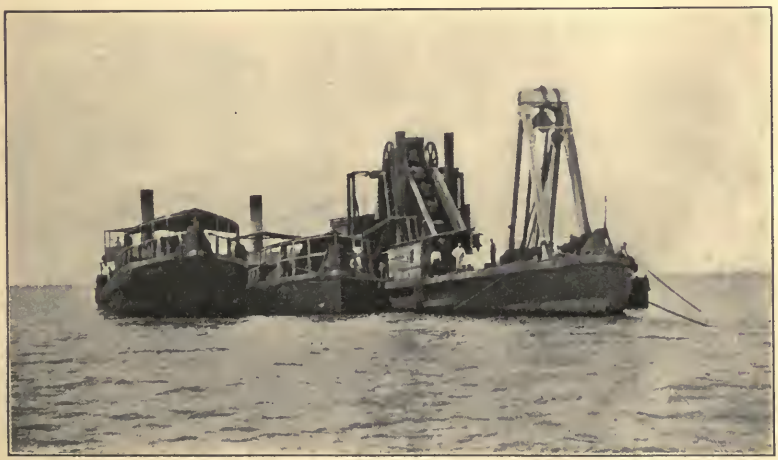
The commission of 1904, therefore, entered at once upon the collection of additional data and hoped to be able to reach an intelligent conclusion relating to the type of the canal at an early date. The published proceedings of the commission show that on December 8, 1904, seven months after the United States had taken possession of the canal properties, it was resolved to send the committee on engineering, consisting of Professor W. H. Burr, Wm. Barclay Parsons, and Major B. M. Harrod to the isthmus

to see that the necessary surveys and data for determining the type of canal have been completed and to bring the same to Washington to be laid before the commission; and that the committee on engineering plans shall, if possible, recommend to the commission, during March, various plans and estimates for the several types of canal, so that the commission as a whole may determine the same.

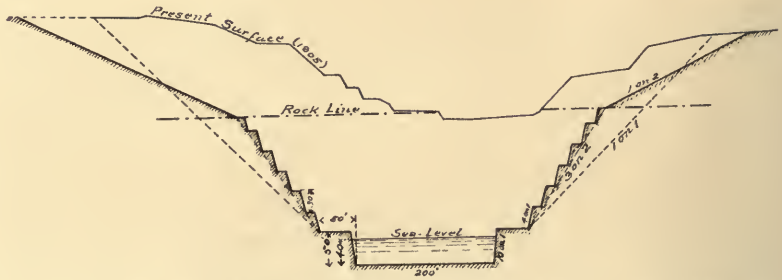
The writer was a fourth member of the committee on engineering plans.

In compliance with this resolution two members of the committee, Professor Burr and Mr. Parsons, went to the isthmus, where their deliberations were participated in by General Davis, who by virtue of his station on the isthmus was a member of all committees there in session. Major Harrod did not accompany the other members of the committee, because it was necessary to preserve a quorum of the commission at Washington for the transaction of business.

On February 23, 1905, the committee, having returned from the isthmus, made a report, in which it recommended that the construction of a breakwater at the entrance of Limon Bay should be commenced at the earliest practicable date; that the harbor at Cristobal should be deepened and otherwise improved; that, if a lock-canal be constructed the summit level of the canal should not exceed 60 feet; that Chagres River should be controlled by a dam at Gamboa; and that a plan for a sea-level canal, free from the restriction of locks (except a tidal lock near the Pacific Ocean) should be adopted. The committee included in its recommendations 150 feet as the least bottom-width of the canal and 35 feet as the least depth, suggesting, however, that estimates be also made to cover a depth of 40 feet. The committee also took up the question of the necessary lock dimensions, if locks be required, and advocated a width of 100 feet and a usable



OLD FRENCH LADDER OR ELEVATOR DREDGE DEEPENING ENTRANCE CHANNEL IN THE PACIFIC NEAR LA BOCA. This dredge is being served by two old French self-propelling hopper barges, known as "clapets."



TYPICAL CROSS SECTION ADOPTED BY THE BOARD OF CONSULTING ENGINEERS FOR THE CULEBRA CUT. K. 54.41.

length of 1,000 feet, but with intermediate gates to conserve time and water. The committee called attention to the increasing difficulties of constructing a dam at or near Bohio, disclosed by additional borings, and condemned as impracticable a dam at Gatun where borings to 172 and to 139 feet below sea-level did not reach bed-rock.

The data, which the commission had instructed the committee to bring to Washington, were not submitted with the report, neither did such data accompany a progress report of the chief engineer, Mr. John F. Wallace, which was received a few weeks later. The type of canal was, however, quite fully discussed by Mr. Wallace, and his report contained the recommendation

that no temporary or tentative plan be adopted that will interfere with the final adoption of the "sea-level plan," which it is hoped will ultimately receive the favorable consideration of the commission.

The committee report, however, brought before the commission a definite recommendation, relating to the type of the canal. In the

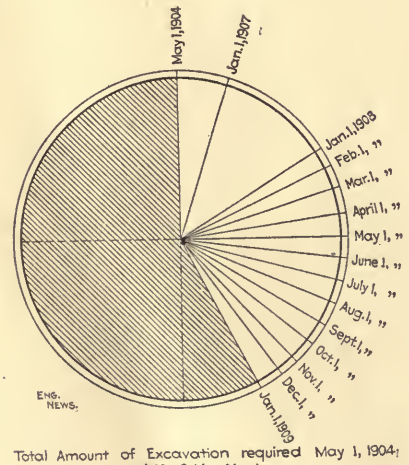


FIG. 1. PROGRESS OF EXCAVATION ON THE PANAMA CANAL UNDER THE UNITED STATES, AS COMPARED WITH TOTAL EXCAVATION REQUIRED.

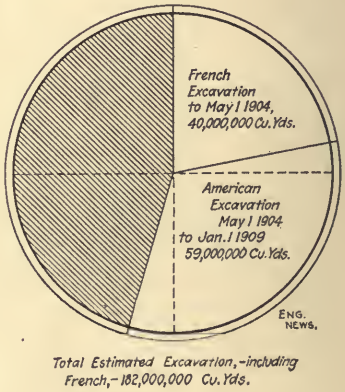


FIG. 2. DIAGRAM SHOWING RELATION OF FRENCH AND AMERICAN EXCAVATION ON PANAMA CANAL TO TOTAL ESTIMATED AMOUNT.

absence of the data necessary to reach a final conclusion on this point, and in view of the fact that no embarrassment would result from a deliberate weighing of all the facts, the writer, though with a pronounced leaning toward the sea-level type, could not see his own way clear to an immediate concurrence in the conclusions of the committee. There was nothing convincing either in the report of the chief engineer nor in the report of the committee relating to quantity of material to be excavated nor in relation to probable cost. The writer did not then believe, nor does he now believe, that the steep slopes where the cut is deepest, as suggested by the committee, nor as incorporated in the plans now being carried out, can be adhered to.[1] There will have to be taken out ultimately very much more material than heretofore assumed at Culebra. This fact coupled with the concentration of the great mass of the excavation in a relatively short central section of the canal, which rendered preliminary estimates of time and cost of the removal of this material uncertain, was a factor that could not be ignored. When, therefore, at a meeting of the commission in March, 1905, it was proposed by Major Harrod that the recommendation of the committee be adopted and that the commission decide in favor of the sea-level canal the writer was not prepared to go so far and the committee report was referred to the committee on engineering plans, of which he was a member, for further consideration.

From these facts, as recorded in the printed proceedings of the canal commission, it might be inferred that at that time Major Harrod was in favor of the sea-level type of canal and that the writer favored the lock type. But the writer's stand was taken, as explained, to prevent action based on inadequate data, while Major Harrod is found eight months later among the members of the second canal commission who determined that the lock plan of canal, as recommended by the minority of the board of consulting engineers, is the one that should be carried out. And now the writer, after having had several years more time for reflection, and in the light of such additional information as has come to hand, is not yet convinced that the wisest course was pursued by the later commission, by the secretary of war, by the president and by congress when the findings of the majority of the board of consulting engineers, eight to five, were disregarded and the plans for a lock-canal project, as recommended by the minority, were adopted.

Before the committee on engineering plans made a report the Walker commission was superseded by the commission of 1905, whose powers were concentrated in an executive committee of three, at the

[1] Since this article was written information has been received that there has been much flattening of slopes. The standard section as shown in the illustration elsewhere presented is therefore no longer strictly typical of the section to which the canal will be finished.

VIEW IN CULEBRA CUT, NEAR EMPIRE, LOOKING SOUTH.

head of which, with dominating influence in the commission's executive affairs, was Mr. T. P. Shonts.

This commission was appointed on April 3, 1905. Two months later President Roosevelt named a board of consulting engineers, to whom he submitted the question of canal type. Thirteen engineers accepted the invitation to participate in the deliberations of this board of engineers.

The board, as finally constituted, consisted of: Geo. W. Davis, Major General U. S. Army (retired), chairman; Alfred Noble, chief engineer of the East River Division P., N. Y. & L. I. R. R.; Wm. Barclay Parsons, chief engineer of the New York Subway; Wm. H. Burr, professor of civil engineering, Columbia University; Henry L. Abbot, Brigadier

STEAM SHOVELS LOADING LEDGERWOOD FLATS ON EAST SIDE OF CULEBRA CUT JUST SOUTH OF GOLD HILL.

General U. S. Army (retired); Frederic P. Stearns, chief engineer of the Metropolitan Water and Sewerage Board, Boston; Joseph Ripley, general superintendent of the St. Mary's Falls Canal; Isham Randolph, chief engineer of the Sanitary District, Chicago; Wm. Henry Hunter, chief engineer of the Manchester Ship Canal; Eugen Tincauzer, Königlich Preussischer Regierungs-und-Baurath, Königsberg, Germany; Adolphe Guérard, inspector général des Ponts et Chausseés, France; E. Quellennec, chief engineer des Ponts et Chausseés and consulting engineer of the Suez Canal Company, France; and J. W. Welcker, Hoofdingenieur, Directeur van den Ryks-Waterstaat, The Netherlands.

On this board of engineers were the three members of the first canal commission,[2] General Davis, Professor Burr and Mr. Parsons, who a few months before had submitted a recommendation favoring a sea-level canal. Other members of the board were known to favor a lock canal. The members of the board therefore naturally fell into two groups of which one was friendly to the sea-level, the other to the lock type of canal, and to the committees appointed from these groups was assigned the task of discussing the canal problem from the two divergent standpoints. The board as a whole, however, passed on certain features in order that the conclusions thus reached might serve as a guide in determining other features of the projects. Thus it was resolved that locks should have a usable length of 1,000 feet, a width of 100 feet and a depth of 40 feet. The board determined, too, upon the type and dimensions of the canal section which should be made the basis of a comparison of cost estimates.

The consulting engineers visited the isthmus and thus learned much, by personal observation, of the conditions under which the canal work must be prosecuted.

As a result of their studies the members of the lock-canal committee of the board of engineers submitted four projects. Two of these were for a canal with a summit level at 60 feet and the other two for a canal with its highest section at 85 feet.

Other projects for the lock-type of canal were presented by Mr. Lindon W. Bates, by Mr. P. Bunau-Varilla and by Major C. E. Gillette, of the engineer corps of the U. S. Army. Mr. Bates presented three projects with a preference expressed for a plan including a terminal lake at each end of the canal, of which the lake at the Atlantic end was to be formed by a dam at Mindi and the lake at the Pacific end by dams from Ancon to Sosa Hill and from Sosa Hill across the Rio Grande. Under this project there would also be an intermediate lake, formed by a dam across the Chagres River at Bohio. The summit level suggested was 62 feet.

[2] Of the other members of the first commission Admiral Walker had returned to private life, Major Harrod had been named on the second commission and the writer had accepted the position of chief consulting engineer in the Reclamation Service under the Secretary of the Interior.

LAS CASCADAS SLIDE, CULEBRA DIVISION, APRIL, 1908. AREA OF SLIDE, 5,433 SQUARE YARDS. Estimated amount of material in motion, 100,000 cubic yards. This slide started in the dry season and extended back 230 feet from the edge of cut and to within 50 feet of the crest of the hill.

Mr. Bunau-Varilla, a civil engineer who was at one time chief engineer, of the Panama Canal Company, proposed a project with a summit level at 130 feet; but with all locks so arranged that there could be a gradual progress of excavation and deepening of the summit level with a successive cutting out of locks until finally the lock canal was converted into a sea-level canal.

Major Gillette advocated a lock canal with its highest section at 100 feet above sea-level.

The sea-level canal committee of the board of engineers reported in favor of a canal 40 feet deep, with a bottom width of 150 feet in earth, and side slopes adjusted to the nature of the ground so as to give a surface width of 302 to 437 feet. The bottom width in rock was to be increased to 200 feet and the surface width in rock was to be 208 feet. At the Pacific end the canal was to be protected by a tidal lock located between Ancon and Sosa hills. The plans, as proposed by the committee, included a dam at Gamboa across Chagres River of either masonry alone or of earth and masonry combined. This dam was necessary for the control of the river.

The dimensions of the canal of the committee project at the point of deepest cutting near Culebra are as follows: Bottom width, 200 feet; the banks to have a batter of 1 in 10 rising from the bottom to a berm 10 feet above the water surface; the berm to be 45 feet wide (according to diagram; 50 feet according to text of report); then a succession of bank slopes with a batter of 1 in 4 and a rise each of 30 feet, one above the other, with intermediate berms each 12½ feet wide up to the rock line—shown by a diagram for the point known as Kilometer 54.41 in

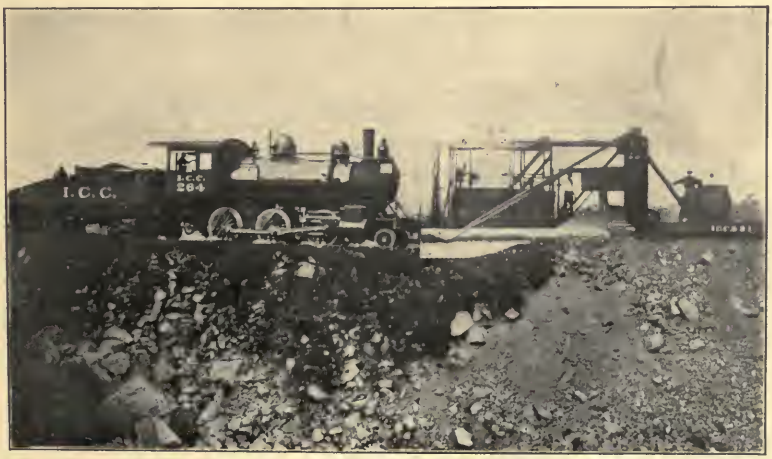
Culebra cut at about 170 feet above the water surface—thence to the natural surface with a rise of one foot in two.

In the course of its deliberations the board of engineers passed favorably upon the feasibility of a canal of either the lock or sea-level type. It determined that a lock canal with summit level at 60 feet should be the basis of comparison of the lock with the sea-level type. It reached the conclusion that about 10 to 11 years should be the time assumed to be necessary for the construction of a lock canal, with summit level at 60 feet, and about 12 to 13 years for the construction of a sea-level canal.

The quantity of material of all kinds to be excavated in constructing a sea-level canal was estimated at 231,026,000 cubic yards, and the estimated cost of making the excavation was $183,136,000.

Among the important considerations bearing upon the selection of the best canal type the board of consulting engineers, as noted in the majority report, says:

> The canal will provide the one great maritime highway, not between seas, but between oceans; not for countries, but for continents. The vastness of the interests to be served by the canal, many of which interests now wait for their development on the construction of the waterway, demands that the canal shall, when opened for traffic, be of the type which will most perfectly fulfil the purposes which the waterway is intended to accomplish.
>
> First and foremost it is essential that the Panama Canal shall present not merely a means of interoceanic navigation, but a means of safe and uninterrupted navigation on which no special hazards will be encountered by and no vexatious delays will be occasioned to the vessels which will traverse it. It is therefore evident that the canal ought to be formed in such manner that the course thereof shall be free from all unnecessary obstructions, and that no obstacles should be interposed in that course, whether temporary or permanent, which would by their very nature be an occasion of peril and of detention to



Spreading Material on the Corozal Dump.

passing vessels, and more particularly to vessels of the great size which the Panama Canal is designed to accommodate.

The board is of opinion that this consideration should be of determining force in respect to the type of canal to be adopted, and that it should lead to rejection of all proposed plans in which lift-locks, whether few or many, form the principal or dominating features, and consequently to the acceptance of the sea-level plan as the only one giving reasonable assurance of safe and uninterrupted navigation.

The majority then set forth that no canal with locks can fulfil these requirements and that the sea-level canal is the only type of canal that can give reasonable assurance of safe and uninterrupted navigation. They refer to three accidents in the preceding nine years arising from collisions between steamers and lock gates on the "Soo," and to three accidents of a like nature on the Manchester Canal, and to the disastrous results that would have followed such accidents at the locks

TRESTLE DUMP JUST OUTSIDE OF EAST TOE OF THE SOSA-COROZAL DAM. Ancon Hill and Ancon Hospital buildings in the background.

of larger dimensions and higher lift on the Panama Canal. They placed the estimated cost of a sea-level canal at less than $250,000,000, and thought that it could be completed in twelve to thirteen years. They strongly condemned any provisional treatment such as the construction of a lock canal.

It is interesting to find among these members Mr. Hunter, the chief engineer of the Manchester Ship Canal (which is a lock canal), who in a convincing statement explains why, although as a member of the Comité Technique, he favored the lock canal as best suited to the conditions under which the New Panama Canal Company was operating, he is now in favor of the sea-level canal.

As an offset to the recommendation of the majority, a minority of five members, Noble, Abbot, Stearns, Ripley and Randolph favored a lock canal for the following reasons:

Greater capacity for traffic than afforded by the narrow waterway proposed by the board.

Greater safety for ships and less danger of interruption to traffic by reason of the wider and deeper channels which the lock canal makes possible at small cost.

Quicker passage across the Isthmus for large ships or a large traffic.

Materially less time required for construction.

Materially less cost.

The project recommended by the minority, which is the project as now being carried out (except for an enlargement of the locks, a change of lock locations, and the abandonment of the proposed dams on both sides of Sosa Hill at the Pacific end of the canal), includes a dam at Gatun, but none at Bohio, and no dam at Gamboa. The locks were to be 95 feet wide, 900 feet long, and the depth of water was to be 40 feet. The summit level was fixed at 85 feet.

Under the minority plan there were to be at the Pacific end of the canal duplicate locks of one lift of 31 feet each, and twin locks in flights of two at Sosa Hill.

The time required to construct the lock canal was estimated by the minority at about six years less than would be required for a sea-level canal, and the cost of the canal is estimated by them at $139,705,000. They say in their report:

The greater cost of the proposed sea-level canal—upward of $100,000,000 more than that of the lock canal herein advocated—is not a trifling sum even for the resources of the United States. If such an outlay is incurred a greatly superior waterway should be obtained or the expenditure will be unwise and the result discreditable.

The minority then present their views at length, calling attention to the small risk of injury to a well-equipped canal lock; to the equal facility of protecting the canal against injury in time of war, no matter what its type; to the greater liability of delay and injury to shipping in traversing artificial channels at considerable speed than in moving slowly under perfect control through locks; to the greater speed at which the open water above the locks can be navigated; to the reduced time that will be required in the passage through the canal with locks; to the greater amount of traffic that would at the outset be provided for; to the provisions that can be made to prevent accidents at the locks; to the extraordinary dimensions proposed for the earth dams at Gatun and at Sosa Hill; to the fact that time required to make Culebra cut and to construct the locks is about the same. They estimate that six years less time will be required to build the lock canal than to build a sea-level canal.

At the time, January 10, 1906, the board of consulting engineers submitted their majority and minority reports to the Isthmian Canal Commission, the membership of the commission was as follows: T. P. Shonts, chairman; C. E. Magoon, governor of the Canal Zone; Rear

Admiral Mordecai T. Endicott, civil engineer, U. S. Navy; Brig. Gen. Peter C. Hains, corps of engineers, U. S. Army (retired); Col. Oswald H. Ernst, corps of engineers, U. S. Army (retired); and Benjamin M. Harrod. A vacancy in the commission that had been caused by the resignation of Mr. John F. Wallace had not been filled.

This commission determined on February 5, 1906, by a vote of five to one, to recommend to the president the lock canal project of the

LIMON BAY FROM THE DE LESSEPS HOUSE. Sketched April 10, 1904. The ships at anchor are the *Newark*, the *Montgomery* and the *Marietta*, all of the U. S. Navy.

minority of engineers. The dissenting member was Admiral Endicott, who favored the adoption of the sea-level project.

The recommendation of the commission was accompanied by a report of Mr. John F. Stevens, their chief engineer, who favored the lock-canal plan.

The secretary of war approved the recommendation of the commission and the president was not slow in acting. On February 19, 1906, the reports and papers were transmitted to Congress with a statement of his conclusions that the type of canal to be built is the canal with locks.

On June 21, 1906, the senate, by a vote of 36 to 31, passed an act authorizing the construction of a lock canal. This act was a few days later concurred in by the house without division. It provided

> That a lock canal be constructed across the Isthmus of Panama connecting the waters of the Atlantic and Pacific oceans, of the general type proposed by the minority of the board of consulting engineers, created by order of the President under date of January 24 (June 24), 1905, in pursuance of an act

entitled "An act to provide for the construction of a canal connecting the waters of the Atlantic and Pacific Oceans," approved June 28, 1902.

It has already been stated that the minority of the board of engineers recommended that the locks be made 95 feet wide with a usable length of 900 feet. The canal commission determined that larger locks would be desirable and fixed the width at 100 and the usable length at 1,000 feet. This action did not, however, satisfy the U. S. Navy. The question of still larger locks was agitated and resulted in action by the naval authorities upon whose suggestion it was finally decided to increase the width of the locks to 110 feet. The depth of water in the locks is to be about 41.5 feet; this will be the depth in fresh water which will be equivalent to 40 feet in salt water.

Since the final and specific approval of the lock-canal plan by Congress all the work on the isthmus has been directed to the rapid construction of this type of canal. Before presenting a few of the salient facts relating to the progress which has been made, a brief review will be given of the opinion expressed by some of the experts whose views were considered in reaching the conclusion that under all the circumstances it was best to build a lock canal.

It should be stated in this connection that the earlier conclusion of the Comité Technique, which was an advisory body to the New French Canal Company, favoring a lock canal, can be given but little weight, as an influence upon the later conclusion, because the advice of that committee was given to a private company operating under a concession with a time limit, and it was compelled to give paramount weight to the financial aspect. A canal had to be built under restrictions of time and cost, and it was to be made a profitable venture. It is not surprising, therefore, that under the new conditions, one of the members of that committee, Mr. Hunter, is found in 1905, as already stated, among those who advocate the sea-level canal.

Mr. John F. Wallace, a past president of the American Society of Civil Engineers, who was called from the position of chief engineer and manager of the Illinois Central Railroad to the position of chief engineer of the commission of 1904 and was later made a member of the commission of 1905, in addressing the board of consulting engineers pointed out:

> That the most desirable transportation routes are straight and level. Variation from the ideal may become necessary to overcome obstacles of a physical, financial or other nature. The plan usually selected is the one in which the sum obtained by adding the interest on cost of construction to the annual cost of maintenance and operation is a minimum. In the case of the canal the feature of future development should not be overlooked and any variation from the ideal of a straight or sea-level canal should only be made after the most mature and careful consideration and for the gravest of reasons. Minor deflections from a straight line are comparatively immaterial as compared with variations of levels.

NORTHEASTERLY ACROSS THE GATUN DAM SITE. Sketched in 1904.

Mr. Wallace formulates certain propositions which he considers fundamental and others which are essential in arriving at the most desirable plan of canal. He says that the most desirable canal is the sea-level canal of such dimensions as would afford unrestricted passage for the largest vessels afloat, with such margin for increase in size and draft as can reasonably be anticipated, making allowance for unexpected developments. No plan should be adopted that would prevent the ultimate construction of a sea-level canal at least approximately approaching to the final idea of the Straits of Panama. Time and cost should be considered to the extreme limit before determining upon a plan which would interfere with this ultimately desirable accomplishment. It is highly desirable that no dams should be constructed the foundations of which can not be carried to bed rock, or at least impervious curtain connection be made therewith. No high dam should be constructed, the destruction of which, by accident or design, would close navigation through the canal until its restoration. If it is absolutely essential to the project that such dams be constructed, they should retain the lowest possible head of water and be of such a nature as not to require the use of experimental, new or untried methods of construction. If terminal lakes are to be formed, the dams creating them should be as low as possible imposing the minimum weight upon the subsoil. The construction of even a low barrage at the Rio Grande Delta would undoubtedly encounter innumerable difficulties in crossing localities where the sub-formation would be such as to give way under the imposition of the weight of material placed thereon. The same obstacle would probably be met to a greater or less extent in the construction of a dam, particularly a high one, in the vicinity of Gatun. The entire valley to at least a depth of 200 feet is alluvial. It is therefore, highly improbable that in the heterogeneous mass of material with which the ancient gorge is filled, particularly near the surface, that unforeseen difficulties in securing proper foundation would not be encountered.

Mr. Wallace repeats to the board of engineers the recommendation which he had already made of the canal commission, that no temporary or tentative plan should be adopted that will interfere with the final adoption of the sea-level plan.

Mr. Quellennec, of the board of consulting engineers, at a board meeting on November 18, 1905, explained his stand in favor of a sea-level canal, stating that it was undeniable that a sea-level canal is preferable to a high-level multi-lock canal both with a view to safety and to facility of operation. He referred to his experience on the Suez Canal which has convinced him of the advantages offered by a sea-level canal. In spite of greater time and cost, he believes the sea-level canal at Panama should be constructed, but in making this statement

he does not wish to be understood as saying that a lock canal is not practicable.

At the same meeting, Mr. Hunter, of the Manchester Canal, gave expression to his views on the type of canal, explaining that although as a member of the Comité Technique he favored, under the circumstances then prevailing a lock canal, he could not under the altered conditions "undertake the responsibility of joining in a recommendation to the United States for the construction of a lock canal. . . ."

Advocating the adoption of a lock-canal project, on the other hand, Mr. Noble said:

I believe the lock canal affords quicker construction, that the wider and deeper waterways it provides would give better navigation; that the transit of ships would be quicker and that the lock canal would have even a greater capacity for traffic than the narrow waterway proposed by the sea-level canal committee.

Another advocate of the lock type of canal, Mr. Ripley, concurred in the remarks of Mr. Noble and gave as an additional reason for his position the belief that this type of canal would provide for a navigation the limit of which will not be reached in a number of years probably 40 to 75 years, so that the people of the United States will not soon be called upon to make additional expenditures for improving the canal; whereas for a sea-level canal it is quite probable that within a short time, possibly 15 or 25 years, a widening will be necessary which will cost many millions of dollars.

Mr. Parsons, also of the board of engineers, referred to the fact that a canal was to be built for all time, that it was a work of the greatest constructive magnitude ever undertaken. The plan of the canal should be of the broadest and largest possible type which we can conceive. A few years more or less in time is of no consequence. Neither is an additional cost of $50,000,000 or even $100,000,000 of importance, as there will be an adequate return. Accidents similar to those which have occurred on the Manchester and the "Soo" Canals have occurred also in the Welland and other canals. These accidents by great good fortunes have not been disasters. With locks of large size

of the size now contemplated the results would have been more serious. It is not the danger to the ship itself that I have in mind, . . . but the danger to the canal. If at one of these big locks an accident should happen, such as has happened at other locks and as will happen here, and a ship should go plunging through and carry away the safety gates and every other mechanical device for protection, releasing the lake of water that lies behind those locks, the section of the canal between that lock and the ocean terminas would be so destroyed that it would take anywhere from one to five years to put it back in service again. The terminal port itself would be gone, the canal would be out of use, the world's traffic would be deranged and the difference in cost of the two types would be wiped out in a few seconds of time. That risk a great government can not be justified in taking.

With these views before him, and in the light of all the information

then at his command, the president reached the conclusion that a canal with locks would best fulfil all requirements, and says in transmitting the board report to the Congress:

> In my judgment a lock canal as herein recommended is advisable. If the Congress directs that a sea-level canal be constructed, its direction will of course be carried out. Otherwise the canal will be built on substantially the plan outlined in the accompanying papers, such changes being made, of course, as may be found necessary, including possibly the change recommended by the Secretary of War as to the site of the dam on the Pacific side.

When the matter was before the senate committee on inter-oceanic canals, another opportunity was provided for the expression of views by experts. At these hearings, Professor Burr said that he was as strongly in favor of the sea-level canal as he ever had been.

> The more I reflect upon it, the more it seems to me that that plan is the one which the United States Government should adopt.

In discussing the Gatun dam, which is a feature of the lock-canal project as adopted, he says:

> It is proposed to build this dam by simply clearing off the surface material and then spreading the earth, suitably selected from the canal excavation, in layers, and so building it up to a height of 135 feet, making its base something like half a mile wide.[3] In my judgment, that is a dangerous experiment on a colossal scale, which this government is not justified in undertaking.

Continuing, Professor Burr states that he has no objection to earth dams under suitable conditions if properly designed and founded. Anything like a flow of water through the permeable material under the dam should be prevented. No suitable means for accomplishing this are provided in this design. He indicates measures that are ordinarily taken to check the flow of water under a dam, and instances several failures of earth dams. In speaking of the dams near LaBoca resting against Sosa Hill, the construction of which was subsequently undertaken, but owing to the yielding, unstable character of the marsh lands on which they were to rest, have been abandoned, Professor Burr says:

> The dams on the Pacific side are smaller, and the risks, perhaps, may be of less magnitude; but they are of the same character, and there is the same objection to them, in my opinion, This dam between LaBoca and the high ground opposite would be founded largely upon the most slippery kind of mud. Any one who has been there and has seen the bottom of the Rio Grande estuary exposed at low tide, I think will agree with me that it is a very lubricating material; and if you were to put a bank of earth on it, even if it were half a mile thick, I think it would be in great danger of being pushed out bodily.

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In speaking of the operation of locks, he calls attention to the fact that the experience at the lock at St. Mary's Falls is not a safe guide for reaching conclusions regarding the safety of six such locks as will be required for the Panama Canal. Their lift is 50 per cent. greater,

[3] As now contemplated, the dam is to be constructed by the hydraulic fill method.

and the dangers increase at a more rapid rate than proportional to the lift, and the dangers are magnified by the fact that the locks are to be in flights. He furthermore reaches the conclusion that the traffic capacity of the lock canal should be estimated at about 35,000,000 tons per annum instead of at 80,000,000 tons, the figure assumed by the minority.

An extended and comprehensive argument for a sea-level project was presented to the senate committee by General Davis, who, as a member of the commission of 1904, and resident on the isthmus as governor of the Canal Zone for a year, and thereupon as chairman of the board of consulting engineers, had had unusual opportunity for arriving at a mature conclusion. All that General Davis said in relation to the type of the canal before the committee should be read by those who desire to follow this matter farther. Short extracts, and a condensed statement embodying the substance of his presentation, can alone be here attempted.

What the situation demands is well known, and the American government has declared to the world that the obstacle at Panama shall be removed. Will it be removed if we leave a hill over which the world's commerce and navies are to be hoisted? Will the world consider that we have adequately solved the problem, and will the American people be satisfied with the result if we offer them anything inferior as respects capacity, or convenience, or adaptability for enlargement, or type, to what capital did for the old world—a canal which now serves as a model, and will continue to, until we acquit ourselves of the responsibility voluntarily and eagerly assumed.

General Davis compares the Soo Canal, with its few thousand feet of channel approaches, to the great tidal harbor basins of Europe. It is more nearly analogous to these than to a great interoceanic canal on which the aggregate length of locks alone exceeds by nearly a mile the entire length of the Soo Canal. Because Lake Huron is twenty odd feet higher than Lake Erie, it was useless to hope for a channel clear of all obstructions, and American and Canadian engineers have provided the best solution possible.

At first, locks 350 feet long sufficed. Then one 515 feet long was added. Next, the first were demolished and replaced with a lock with a chamber 800 feet long. Then the Canadians made another in their territory 900 feet long; and we are about to demolish our second lock to put in one 1,400 long. . . . The critics of the majority report admit that a canal at sea-level would have certain advantages. I think it may be said that one and all concede that if a sea-level waterway be wide and deep enough, it would be superior to any involving excavated lakes, locks and lifts; but they discard it as impracticable because of the greater cost.

The better approach to the straight line requirement by the sea-level canal is pointed out. The lock canal project shows 21 per centum more winding and tortuous navigation than the sea-level project. General Davis estimates the expense of maintenance and operation of a sea-level canal at $1,550,000 per annum, and the lock type of canal, at $2,-

150,000. The cost of the government of the Canal Zone, estimated at $100,000 is not included in these figures. Relating to dimensions, and other features of various canals, data were presented in tabular form, in part as here reproduced.

EXISTING AND PROPOSED CANALS

	Units	Panama Sea-level	Panama Lock	Suez Now	Suez Enlarged	Kiel
Total length	Miles	49.35	49.72	94.76	94.76	57.89
Straight portion	Miles	30.18	42.25	81.73	81.73	
Curved portion	Miles	19.17	7.46	13.04	13.03	
Curved portion	Per cent.	38.8	15.0	13.8	13.8	40.9
Depth	Feet	40	40	31.2	34.4	29.52
Least bottom width	Feet	150	200	108.26	147.63	72.17
Least bottom width in curves	Feet	150	250	131	160[4]	75.2
Least cross-section	Sq. feet	8,160	8,160	5,813 6,025	7,741 8,144	4,444
Total curvature	Degrees	597	637	467	467	
Curves	Number of	19	24	15	15	26
Locks	Number of	1	6	0	0	2
Locks, length	Feet	1,000	900			492
Locks, width	Feet	100	90			82

[4] Approximate.

The enlargement of the Suez Canal is not yet complete. The total length of the Suez Canal is 104.8 statute miles, of which about 10 miles are in lake, leaving the length of the excavated channel 94.76 miles.

The total length of the Kiel Canal is 60.89 miles, of which 3 miles are in lakes. Where two sets of figures are noted for the area of the cross-section, one applies to low, the other to high water.

General Davis shows that the proposed sea-level canal will not be dangerous, narrow or contracted, because this is not true of the Suez Canal, which is longer, narrower and shallower, and has more abrupt bends than the canal proposed by the majority of the engineers. He calls attention to the fact that in the opinion of very able engineers the cost in time will be but slightly more for the channel at ocean level, than for a canal with a summit level at 85 feet; and he says:

> It is certain that the cost in money of the simple low-level channel in which every existing and projected vessel would find convenient passage, will cost some tens of millions more than the complicated high-level structures, but the former will closely approach and ultimately result in the ideal, simple natural waterway . . . while the latter will stand for the opposite until heroic measures are resorted to and the objectionable structures are removed, for the idea of transformability is eliminated by the majority.

Col. Oswald H. Ernst, of the Engineer Corps, U. S. Army, a member of the canal commission of 1905, said in part:

> I have made a very careful review of the arguments presented on both sides, as exhibited in these two reports which you have before you—the majority and the minority reports—and I am satisfied that the United States will get a

perfectly satisfactory canal in very much less time, and for very much less money, under the plan proposed by the minority. I believe that the canal under that plan will cost little more than half what the canal of the majority will cost, and the time will be a little more than half, and when done it will be a better canal, because it will be three times as big a canal. The volume of water in the sea-level canal is only one third what the volume of water is in the lock canal. Leave out everything in those lakes beyond the width of 1,000 feet, and everything beyond a depth of 45 feet, and you have three times the number of cubic yards of water in the lock canal that you have in the sea-level canal.

Among the earliest and best-informed advocates of the lock canal is General Henry L. Abbot, of the Corps of Engineers, U. S. Army (retired), who was a member of the Comité Technique, and was also a member of the board of consulting engineers. General Abbot has been a close, able and careful student of the hydraulic and other problems involved, and ever since the days of the Comité Technique has contributed much to the discussion thereof. In presenting his views to the board of consulting engineers, which are at too great length to be quoted in full, he says:

The most important consideration, from an engineering point of view, in projecting a transit route, whether a railroad or a canal, is to adjust the details to the topography and natural conditions of the region to be traversed. On the Isthmus, the Chagres River is the dominating feature. . . . The deep excavation in the Culebra section is a formidable undertaking, chiefly because it will be necessary to transport the soil to long distances; but once executed, it will remain without giving occasion for anxiety in the future. The Chagres is capable of becoming a very active enemy at any future time, unless effectively tamed by good engineering methods.

General Abbot thereupon discusses the peculiarities of this river, and its relation to the several canal projects. He reaches the conclusion that the problem of the control of the Chagres is solved by the lock canal project in a manner at once vastly better and vastly more simple than by the sea-level project. He expresses his judgment, however, that the primary consideration in choosing between the two projects "should be their relative merits as routes for shipping. The elements of time and cost are secondary, but too important to be neglected." According to General Abbot, double the cost and double the time should be allowed for the completion of a sea-level canal, and when completed, the canal would be distinctly inferior to a canal with locks. In the matter of the sufficiency of the flow of Chagres River to maintain the lake above the Gatun dam, at the desired elevation, General Abbot is emphatically of the opinion that the water supply will be adequate. Based on a most

	Cubic Feet per Second
Evaporation loss, estimated	710
Leakage of gates	250
Infiltration	77
For light, power, etc.	200
Contingencies	200
Total	1,437

careful study of all existing data, on the assumption that the water surface of the lake will have an area of 110 square miles, he gives the following figures:

The water available is estimated at not less than 1,225 cubic feet per second natural flow at Gatun during the three months of lowest river stage, and to this amount there are to be added an additional volume of 1,577 cubic feet per second, resulting from a four feet allowable fluctuation of the lake surface. There are then 2,802 cubic feet per second available, of which the difference between 2,802 and 1,437, or 1,365 cubic feet per second, will be available for lockages. This amount of water, according to General Abbot, will be adequate for 26 daily transits. Should there be need for more stored water, the same can be secured by the construction of a dam at Alhajuela, where sufficient water can be impounded to increase the number of lockages by 40, though only 27 have been assumed by the minority.

It is absolutely certain that there can be no deficiency of water for any conceivable traffic demands.

Since the foregoing estimates were made it has been found that the Gatun Lake will have a surface area of about 164 square miles, instead of 110, as assumed. The lock dimensions have also been increased, as explained, and more water will be required for each transit through the canal. The estimates relating to the available water supply as above quoted therefore need revision.

And thus, in the light of the information then available, the type of the canal was fixed in 1906 by action of the Congress of the United States in substantial conformity with the recommendation of the minority of the board of engineers, and for three years the work of construction has been actively pushed.

The progress that has been made is clearly set forth in the records of work done. Measured by cubic yards of excavation it has been highly satisfactory. The graphical presentation herewith is from a recent summary published by the *Engineering News*. It appears from the figures compiled for that summary that the total excavation since the canal became the property of the United States at the close of the year 1908, amounted to 59,980,000 cubic yards, of which 53,161,000 cubic yards had been taken out of the canal prism, and 6,819,000 cubic yards were excavated from the locks and spillway sites and from other points outside of the canal proper. Of the total work, that done by steam shovels (work in the dry) amounted to 37,155,000 cubic yards, and dredges had excavated 22,825,000 cubic yards.

It has been estimated by the canal commission that the total excavation to complete the canal on the lines of the accepted project (not including the work by the French canal companies) is 142,000,000 cubic yards. According to these figures there were about 89,000,000 cubic yards yet to be removed from the canal prism on January 1, 1909.

It should be noted, however, that there has been little deepening of the canal excavation on the backbone of the isthmus,[5] at and near Culebra below the levels reached by the French companies. The work thus far has required the widening of the cut. Whether, hereafter, under the requirement for securing depth the same rate of progress can be maintained, as now shown by the records, is a question which can best be answered by the engineers now in charge of the work. It is probable that the future records will show a gradually decreasing rate of progress if measured by yards of excavation only.

When the building of the dams contemplated by the minority, from high ground at Corozal to Sosa Hill, was undertaken, it was soon found that these structures were ill-advised. The muck and mud of the "Manglares" could not support the load of a moderate fill. There was much settling and lateral displacement and the work was abandoned. This was in no wise fatal to the lock project, because it merely involved the shifting of the proposed locks at Sosa Hill back to Miraflores, where excavation for them is now in progress.

The work on the main dam, the dam at Gatun, has barely commenced. This dam will be of earth; it will have a crest length of about 7,000 feet, and a breadth of base, measured up and down stream, of nearly one half mile. The greater part of the material of which the dam is to be composed will be put in place by the hydraulic method. The material will be transported by water in pipes, and a practically impervious and safe body of earth will thus be deposited across the valley of the Chagres at Gatun. The recent settling and slipping of a rock fill that was being placed along the up-stream toe of the proposed structure is of no great significance. There will be other slips until displacement of layers of yielding material, under and particularly near the edges of such fills, is sufficient to secure stability. The doubts concerning the feasibility of a structure at this point have not arisen from fear of such slips, but from the uncertainty relating to a movement of water at considerable depth under the dam in porous deposits, the extent and permeability of which, notwithstanding information obtained by borings and shafts, must necessarily remain more or less conjectural. It is feared by some that such underflow may threaten the safety of the dam and by others that a serious loss of water may thus result.

All such fears are far-fetched. There is but little basis for them. There can be no injury to the dam from a moderate underflow if suitable precautions are taken to let the water come to the surface at the down-stream toe of the dam through sand, gravel and broken rock

[5] Information is published in the *Canal Record* of February 10, 1909, that the President in October, 1908, authorized the widening of the Culebra section of the canal from 200 feet on the bottom to 300 feet. This fact was not known when the above was written. The process of widening without materially increasing the average depth of this section of the canal may be expected to continue, therefore, some time longer.

deposits, so that it can not displace the earth particles with which it comes in contact in its passage under the dam. To make a convincing estimate of the volume of flow in the porous sub-surface strata under the dam is almost out of the question, because the extent, character and continuity of these strata can not be definitely ascertained, and it will be difficult, if not impossible, to determine at what point or points the water will sink from the lake above the dam into these layers. The engineers can, therefore, do no better than make unfavorable assumptions and determine the maximum water loss that may result under such hypotheses. There is no probability that this will be such as to prove embarrassing to the project. It is to be remembered in this connection that nearly always, when a subsurface flow in a river channel has been developed by the construction of a subsurface curtain or dam, the result in water output has been disappointing. In other words, the probability is that the under-flow will be over-estimated. Nevertheless, the public seems to expect further assurance that the canal work is progressing along proper lines, particularly as it now appears probable that the cost of the lock canal will be more than double the amount named by the board of engineers in comparing the cost of the two types of canal.

In the writer's opinion, it may confidently be assumed that a safe dam can be constructed at Gatun. The situation at Gatun is, therefore, of minor importance in the further discussion of the question that has again arisen: "Would it not still be well to change the approved project and to complete the excavation to sea-level?" This question, if it be again opened, will have to be considered in the light of the views of the experts whose opinions have been herein referred to, in the light of the work already done and the progress already made; in the light of the experience on the isthmus during nearly five years of effective work, and in the light of such additional facts and conclusions as may be submitted by the engineers now about to start for the isthmus.

January 25, 1909.

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